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The Maintenance of Lighting Installations

By W. ROBINSON, B.Sc., A.M.I.E.E. *(Fellow)*
and J. W. STRANGE, Ph.D., A.R.C.S. *(Member)*

Summary

The paper considers lamp replacement and depreciation of lighting equipment as factors in lighting maintenance. Improved ageing characteristics and lighting service provide increased economic justification for group replacement of discharge and fluorescent lamps, and the economics and procedure are discussed.

Recent investigations in this country and the United States into lighting fittings' depreciation have revealed, among other features, that ventilation of open fittings has a decisive self-cleaning effect which profoundly affects the economics of lighting maintenance and the performance of the lighting installation.

A consideration of the various factors, economic and practical, involved in lighting depreciation leads to the conclusion that maintenance should be a primary factor both in lighting design and fitting design.

(1) Introduction

Lighting maintenance can be divided into two main sections, the replacement of lamps and the cleaning of lamps and fittings. The subject could be extended to include consideration of the cleaning or redecoration of walls and ceilings, for these often play an important part in the lighting of small rooms in particular. This aspect is a very difficult one to deal with because it varies so widely and the factors involved do not lend themselves readily to any detailed analysis. We have not, therefore, attempted such an analysis, and the main part of the paper applies to installations where the lamp and fitting alone are the main factors in the maintenance of lighting.

It is worth stating at the beginning that the application of a cost analysis to lighting maintenance is not necessarily the main argument which determines its operation. In many cases appearance is the main criterion, a fitting being cleaned because it looks dirty. Lamps are replaced when they burn out, partly because a " dead " lamp looks bad, quite apart from the reduction in light which results. There is also the important additional argument that a failed fluorescent lamp may, if left unattended, cause damage to the starter switch and ballast. Regular maintenance, including cleaning and lamp replacement, can be justified on a number of grounds of which cost is only one.

Our survey of current practice has shown that in many cases there is no plan, let alone cost analysis, about maintenance. In many small factories and offices the work is done by the odd-job man and the cost is rarely analysed.

The cost approach also fails to find application in quite large factories such as one which was visited during our survey. In this case each large factory block had one or more electricians specifically allocated to maintaining the electrical equipment in that building. All the necessary spares and ladders were on the site and the cost of replacing lamps could not be separated from the cost of other maintenance jobs which were undertaken and any change in that procedure would appear as an additional cost even if in practice it effected economy and reduced the time spent on the jobs concerned.

The main fields of application of cost analysis are (1) *large* industrial installations or office installations where sheer size is the important factor, (2) installations where separate units are scattered widely over a large area and the " *horizontal inaccessibility* " means that the cost of sending maintenance engineers to the different sites has to be

Mr. Robinson is with the British Electrical Development Association and Dr. Strange is with Thorn Electrical Industries, Ltd. The manuscript of this paper was first received on November 10, 1954, and in revised form on November 25, 1954. The paper was presented at a meeting of the Society held in London on December 14, 1954.

carefully planned if it is to be kept at a reasonable level and (3) installations where, due to the height of the fittings and "*vertical inaccessibility*," the same factors operate.

Examples of these types of installation may be (1) a large factory or office building with, say, several hundred fittings reasonably accessible, but in total presenting an appreciable maintenance problem; (2) An office organisation spread among various buildings on a site where the distance from stores and service department mean a considerable cost in time in undertaking even small replacement or maintenance work; (3) Examples of these are lamps over machinery or running tracks of railways and lamps situated in the roofs of tall buildings such as museums or steelworks.

In all these cases a realistic view of the cost of doing any operation on the fittings whether it is replacing a component, a lamp, or cleaning the fittings must be taken. The minimum figure may be several shillings and it may reach figures very much higher than that. The value of planning cleaning at specified intervals and lamp replacement on an orderly basis becomes immediately apparent in such installations, although it is difficult for the ordinary maintenance engineer to assess with any accuracy the most suitable time for these operations. It is the purpose of this paper to examine the various factors which come into the problem with a view to clarifying the position. All the data which is available is still too limited to be able to give any very definite guide, but we hope that this paper will help to stimulate interest in the problem and encourage the accumulation of such data.

Much of what will be said in this paper applies particularly to fluorescent discharge lamps because they are to-day predominantly used in lighting installations of the type referred to. The arguments as far as possible have been kept in a general form and apply generally to lamps of most types. The two aspects of lamp replacement and cleaning will now be considered separately.

(2) Lamp Replacement

If, as so often happens, a lamp is replaced only when it has burned out there is no need for any discussion of costs, etc. The point on which we wish to concentrate is that, in the type of installation which we are considering and with the considerable basic cost of any servicing operation, there comes a time when the value of a lamp based upon its expected life or its "residual value" has reached such a low figure that it is better to replace a group of lamps, at a lower labour cost per lamp, than to continue burning them to the end of their lives and replace them individually. If the difference between individual replacement cost and group replacement cost is greater than the residual value of the lamps then group replacement can be justified on a cost basis.

In all cases which have been referred to there will be a major difference between group lamp replacement and individual lamp replacement. The time taken for electricians to receive instructions, collect spares, replacement lamps and the necessary ladders, etc., take them to a site and carry through the replacement will be only slightly increased by replacing a few additional lamps at the same site. The actual difference will vary greatly but a reasonable estimate is that the labour cost of group replacement of lamps may be as low as 20-30 per cent. of the individual lamp replacement cost.

In one typical case, which was investigated, there was a large office wing lit by 240 80-watt fluorescent lamps in 20 fittings. The fittings were high up on the walls and covered with acrylic plastic covers. Replacing the whole installation took 90 man-hours, using special equipment designed and housed in the building for that particular work. The cost of labour alone worked out at 2s. per lamp. Estimates in that case of the cost of individual lamp replacement were over 6s., but they were exceptionally favourable since the equipment was so readily accessible.

After establishing, for the particular installation, the estimated individual and group replacement costs, the next stage is to assess the residual value of the lamp.

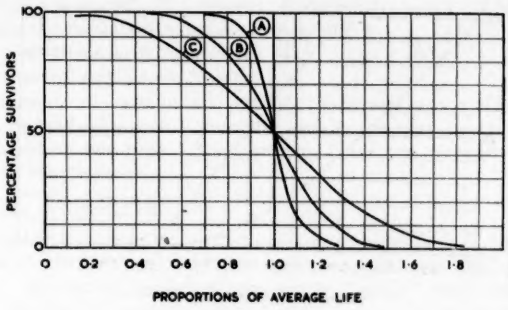

Fig. 1. Survivor curves with different standard deviations.

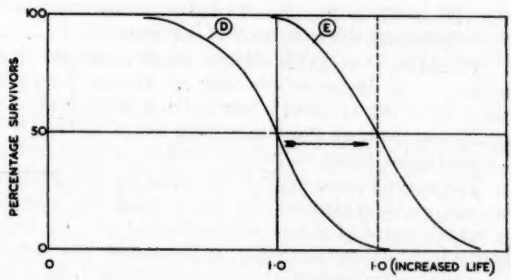

Fig. 2. Survivor curves for batches where the average life has improved.

For that purpose it is necessary to have full information about the life characteristics of a given batch of lamps. It is convenient to show it as a survival or mortality curve plotting the number of survivors against the length of life. To a near approximation the average life of the batch is that at which 50 per cent. are still surviving, but from the maintenance or lighting engineer's point of view this is not enough; it is necessary to know the shape of the curve.

The factors controlling the shape of the curve vary according to the product and are completely different for the two cases of the incandescent and fluorescent lamps. In the incandescent lamp the chief factors are the uniformity of coil dimensions and the length which is clamped to the electrodes, and in this case efficiency is directly related to lamp life.

In fluorescent lamps efficiency has normally little connection with length of life, which depends mainly upon cathode design and the amount of emissive material which is held in the coils of the cathode. In both cases, however, it is the control of manufacture and the securing of close limits that are important factors which determine the shape of the survivor curve.

In Fig. 1 are given three survivor curves all for batches with the same average life but with very different standard deviations; (A) indicates a manufacturing process under very close control, (B) shows one with a wider variation to be expected in practice*, and (C) a process or product which is something of a nuisance both to the manufacturer and the user!

A manufacturer steadily improving the quality of his incandescent lamps may move from (C) to (A) but in the case of the fluorescent lamp particularly, equally well

* Similar figures are reported by Thayer, American I.E.S. Nat. Conf., 1954.

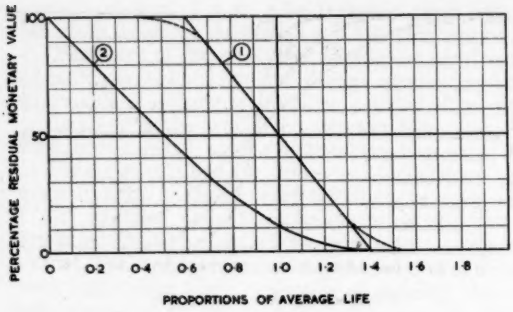

Fig. 3. Residual monetary value and life of batch.

from (D) to (E) in Fig. 2. A similar change can also take place by a change from a 3-hour switching cycle to one of 12 hours.

To obtain a workable scheme which commends itself to the user and to the manufacturer, it is obviously desirable to replace lamps when, from observation of the behaviour of the batch as a whole, the average length of life is approaching, e.g., when, say, 20 per cent. of the lamps have failed. What is the actual point in the lifetime of a particular batch of lamps at which it pays to replace them?

The maintenance engineer is faced by this problem when he may have available only the manufacturer's claim for average life, possibly a typical survivor curve and the actual record of failure of the installation. He may, of course, decide not to worry about the actual performance of the lamps and just take the claimed figure. If this is a conservative estimate he will not benefit fully from the increase in quality.

From the survivor curve and the actual cost of the lamp it is then possible to construct a residual monetary value curve similar to curve (2) in Fig. 3. If we consider a survivor curve for a batch of lamps with an average life of 5,000 hours and a standard deviation of 1,250 hours and neglect the dotted tails of the survivor curve the residual monetary value can be indicated by curve (1) and the proportion of residual value (RV) to initial value (IV) can be expressed by the equation :—

$$\frac{RV}{IV} = \frac{(1.4\ L_m - L)^2}{1.6\ (L_m)^2}$$

when L_m = average life and L = period of operation.

This holds only for periods when L is less than $0.6\ L_m$. For shorter periods

$$\frac{RV}{IV} = L/L_m.$$

Such values will vary widely with different types of lamps. An incandescent lamp with a relatively low cost and fairly short life will be very different in this respect from a fluorescent lamp of higher cost and much longer life. It will be seen also that no figures are given for the actual hours of life; for a given batch they can never be accurately known until a true sample has been life-tested on a similar switching cycle.

One important conclusion may, however, be drawn immediately from the diagram. For products such as hot cathode fluorescent discharge lamps, for which such a survivor curve is typical, the residual value at the point when failures start to occur with some frequency is already so low that it wants little difference between individual and group replacement costs to show an overall advantage. For example, if we use the values in Fig. 3, at 80 per cent. of the average life of the batch, when about 20 per cent. of the

lamps have failed, the residual value is roughly 22 per cent. of the initial value. With information of this type available two main procedures are possible:—

(a) Replacement after a given time of operation.
(b) Replacement after a given percentage failure.

Within these main plans a number of variants are possible, particularly if a close control of illumination levels is desired. In such a case the installation may be split, alternate lamps only being replaced at one time. The London Transport Executive operate such a scheme on some of their stations.

(a) *Replacement after a given time of operation.*

For many installations probably the simplest procedure is to choose one of the times when the fittings are to be cleaned on the normal maintenance schedule and to replace all lamps at that time. All lamps, including apparently "good" ones, are replaced. These can be used if desired for replacements of early failures or in more accessible positions. This method has the great advantage that it can be planned well ahead, and it involves little or no detailed control of lamp replacement to assess percentage failure. It also cuts the actual additional cost of group lamp replacement to a very low figure because most of the cost is already incurred by the cleaning operations.

(b) *Replacement after a given percentage failure.*

This alternative can only be operated if it is possible to get a reasonably accurate check of lamp replacement so as to assess the point at which failures are likely to occur with increasing rapidity, such as, for example, a point where 20 per cent. of the lamps have failed. At this point there is no doubt that the residual value of the lamps is becoming very small, and there is little advantage in maintaining them in service. It only wants a small difference between individual and group replacement costs to justify a complete replacement. This scheme has the great advantage that it utilises to the full the improvements in lamp performance achieved by the lamp manufacturer.

He may be claiming 5,000 hours and may, as the result of manufacturing improvements, be achieving 7,000 hours and the user obviously wishes to reap the advantage of this improvement in quality. It may be worth detailing a suggested procedure for this type of replacement as follows:—

(1) Install new lamps throughout given area.
(2) Replace all early failures such as those due to transit damage by lamps of the same batch at the end of a 100 hours' operation.
(3) For the following period, up to at least 70 per cent. of the rated life, failures should occur only rarely and these should be replaced by clearly marked replacement lamps.
(4) When total replacement or failures have reached some arbitrary figure, say 20 per cent., all the lamps are replaced at the most convenient opportunity. The marked replacement lamps may be used once more only for replacing failures as in all probability their residual value is still high.

One possible criticism may be that the selection of an arbitrary point such as the 20 per cent. failure point is an inadequate guide to the average life and it may be appreciably longer than was expected. In practice, the error is small as we are dealing only with the "tail" of the "residual value" curve given in Fig. 3.

During the preparation of this paper our attention was drawn to a paper[1] which refers to two rather similar schemes. An earlier American publication[2] gives details of a scheme in an insurance office involving 43,000 lamps. These are only a few of a number of possible schemes. The planning and costing may be simple or detailed but in varying degree they all show the considerable advantages which arise from planned maintenance particularly when lamp replacement is combined with cleaning.

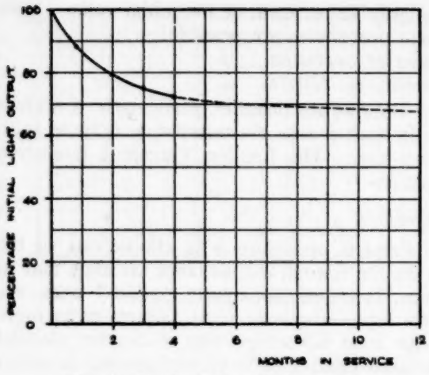

Fig. 4. Typical depreciation curve

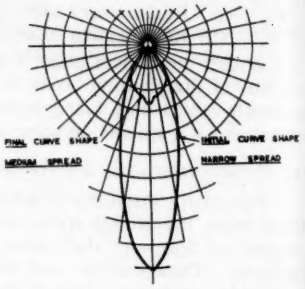

Fig. 5. Changed lighting distribution due to fitting depreciation.

(3) Depreciation of Lighting Fittings

(3.1) General Depreciation Characteristics

It is often assumed that depreciation of lighting fittings due to dirt occurs at a steady rate during the period of use of the fittings or during the time elapsing since cleaning was done. In fact, the rate of depreciation changes throughout these periods.

Fig. 4 shows a typical light output depreciation curve of a reflector in a fairly dirty factory location, in this case an engine assembly area[3]. It will be seen that the curve is steepest during the early months and assumes the expected asymptotic form, shown dotted, only after depreciation has occurred for several months. This relatively rapid initial rate of depreciation from the clean state is an invariable characteristic of the normal industrial reflector and it is very likely that it is connected with the destruction of the specular component of reflection associated with enamelled surfaces. This component may account for 10 per cent. or more of the light output from a clean reflector and even a very thin layer of dust will eliminate it.

This initial effect of dirt deposition is most marked in very dirty conditions whereas in clean conditions no serious error is introduced by regarding the depreciation as linear over a period of 12 months.

Fig. 5 illustrates a further characteristic effect of dirt deposition, viz., the alteration

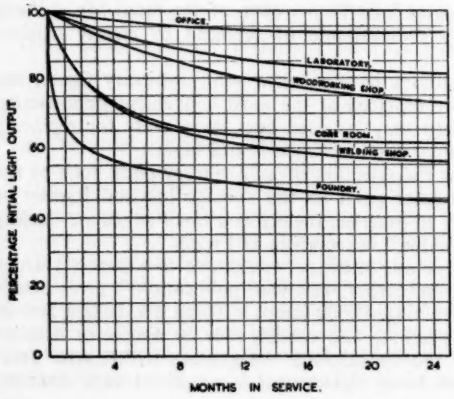

Fig. 6. Variation of fitting depreciation characteristics according to location.

in the light distribution of fittings(4). In the case shown the light distribution has changed from narrow to medium spread due to loss of specularity. The fitting in question had an aluminium reflector and it is to be expected that this effect will be even more pronounced in the case of more highly specular finishes.

Illumination measurements before and after cleaning fittings are clearly only a reliable guide to the light loss due to depreciation if they are properly averaged over the area concerned.

(3.2) Effect of Location

Fig. 6 indicates the wide variation of depreciation characteristics according to location(5). The range between the best and the worst shown is largest in the early months and reduces considerably at the end of long intervals between cleanings. For instance, two months after cleaning the reflectors in a foundry had depreciated nearly 40 per cent. as against 5 per cent. in the woodworking shop, a range of 8 to 1. Twelve months after cleaning the relative depreciation was 50 to 20 per cent., or 2½ to 1. A similar comparison between the woodworking shop and the core room shows this tendency even more emphatically.

It is particularly interesting to note the relationship between months of service and maintenance factors in the various locations. It is clear that the present practice of basing design on a standard maintenance factor of 0.8 requires some examination and this is discussed in a later section.

(3.3) Effect of Ventilation

Fig. 7 shows the result of tests carried out in the United States on the depreciation under identical conditions of fluorescent fittings which differ only in the provision of ventilation(6).

Fig. 8 shows the result of similar tests carried out in the United Kingdom in a

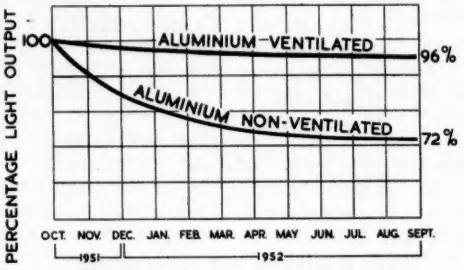

Fig. 7. Effect of ventilation on depreciation of fluorescent fittings.

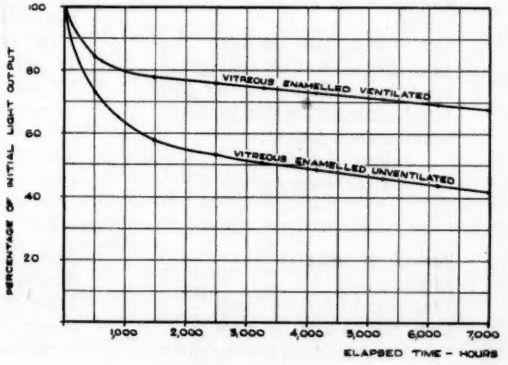

Fig. 8. Effect of ventilation on depreciation of fittings in a foundry (MA/V lamps).

foundry using a ventilated and unventilated (closed and open top) 250-watt MA/V fitting, vitreous enamelled.

These results indicate beyond doubt that ventilation has a markedly beneficial effect on light maintenance and, moreover, that the benefit extends equally to fittings relatively cool in operation (i.e., fluorescent) as to fittings relatively hot in operation (i.e., tungsten filament and discharge). This suggests that the self-cleaning effect operates by convection air carrying dirt particles out through the ventilating aperture rather than by the convection currents being powerful enough to dislodge dust from the upper reflector surface, although no doubt both effects occur in some degree. It is not known whether the self-cleaning effect is mainly dependent on the lamp being alight or to what extent it occurs due to normal room air convection. The magnitude of the improvement and the smoothness of the curves suggests that the effect occurs whether or not the lamp is alight, but there is most probably an additional scavenging effect due to the stronger uprush of air in the lighted fitting and this will operate on the lamp as well. There is undoubtedly room for further investigation into the properties and design of ventilated lighting fittings.

The change in light distribution characteristics, indicated in Fig. 5 for unventilated fittings, has been found to be very much less pronounced in the case of ventilated fittings and is usually negligible in the case of fittings with mixed or spread reflection characteristics, such as vitreous, stove enamel or aluminium.

(3.4) Effect of Cover Glasses

The following are the results of depreciation tests, carried out in this country and reported by J. G. Holmes, on open prismatic glass reflectors, similar reflectors with ungasketted cover glasses beneath the lamp, and fully sealed reflectors.

TEST 1

Period of test:	12 months in a London office.
Fitting:	Open translucent glass reflector.
Loss due to dust on lamp:	8 per cent.
Loss due to dust on reflector:	21 per cent.
Total depreciation due to dust:	27 per cent.
Maintenance factor:	
—before washing	0.73
—after washing	1.00

TEST 2

Period of test:	12 months in a London office.
Fitting:	Enclosed translucent glass reflector.
Loss due to dust on lamp:	5 per cent.
Loss due to dust on reflector:	18 per cent.
Loss due to dust on cover glass:	15 per cent.
Total depreciation due to dust:	34 per cent.
Maintenance factor:	
—before washing	0.66
—after washing	1.00

TEST 3

Period of test:	About one year in a gas works retort house.
Fitting:	Sealed reflector bowl industrial.
Loss due to dirt on lamp:	2 per cent.
Loss due to dirt on glass:	3 per cent.
Total depreciation due to dirt:	5 per cent.

Maintenance factor:

—before washing	0.95
—after washing	1.00

This fitting had apparently been wiped from time to time so as to remove dirt from the outer surface of the glass but it had not been opened for cleaning.

It will be noticed that these tests reveal a marked *increase* in the rate of depreciation due to the addition of ungasketted cover glasses. There can be little doubt that this arises from interference with the direct lamp component which, in an open fitting, is independent of the reflector. The cover glass may prevent *some* dirt from entering but that which settles on the cover under the lamp may be disastrous to the fitting performance. Further tests reported by Holmes indicate that this disability is more marked in the case of dusty than oily atmospheres.

It would appear that ungasketted cover glasses are useless when considered purely from the maintenance viewpoint and this may apply even when gasketted unless they are adequately sealed. Cover glasses may be desirable, however, for other purposes, i.e., appearance or light control or diffusion, and may be left unsealed for reasons of convenience or cost. In such cases it is probably a simple matter to wipe them frequently. There is no evidence that unsealed cover glasses have any marked effect on the rate of reflector or lamp depreciation.

In the case of fittings in high bays or inaccessible positions the matter is more serious, since, even without any attention at all, there will always be a direct component of lamp output from open fittings, whereas the addition of cover glasses which are not properly sealed may result eventually in the loss even of this.

The requirements for adequate sealing are more stringent than is often realised due to the effect of "breathing," i.e., the expulsion of air from the hot interior (the dust from which tends to remain in the fitting) and the suction of air, with its suspended dirt, into the fitting on cooling. This phenomenon is particularly noticeable in the case of enclosed street lighting lanterns which, although well gasketed, are not immune from dust entry. In their case, however, the dirt, which mostly collects on the bottom of the enclosure, does not affect the lighting performance to the same degree as in the case of a fitting directing its light mainly downward.

(3.5) Effect of Dirt on Lamps

These results also show that, over intervals of 12 months, cleaning the lamps has a much smaller effect than cleaning the reflectors. It is likely, however, that similar tests taken after a shorter depreciation period might well show quite a different relationship between lamp dirt and reflector dirt as factors in depreciation. Results obtained in a woodworking shop reveal a significant exception to this tendency. In this case both the lamp and reflector were coated with fine sawdust. The particules were sufficiently light in colour to produce little effect on the reflector while being individually fully opaque to the lamp output. It is clear that where light-coloured dust is predominant simple lamp cleaning has an important part in the cleaning procedure.

(3.6) Effect of Discharge Lamp Burning Position

In the case of vertical burning MA/V lamps in deep bowl reflectors, there is, in any event, only a small component of direct lamp output and hence the lighting performance after continued inattention will be very poor. Fittings with horizontally burning lamps, on the other hand, will continue to provide an appreciable amount of direct lamp light whatever the state of the reflector.

Furthermore, in fittings with vertical discharge lamps the direct lamp component is least at a point directly below the fitting but at points where a view of the lamp is obtained the direct lamp component is higher, depending on the subtended area of lamp seen directly at this point. Reflector depreciation will therefore cause a greater

reduction in illumination immediately beneath the fitting than at points further out. This represents a change in light distribution additional to that due to loss of specularity and illustrated in Fig. 5.

(3.7) Effect of Lamp Operating Hours on Rate of Depreciation

The foregoing depreciation curves have been plotted against elapsed time, and without regard to lamp operating time. There seems to be no general agreement, however, as to whether cleaning schedules should be based on elapsed time or operating time, but it is likely that neither basis alone gives a complete picture of the situation.

The smoothness of depreciation curves based solely on elapsed time suggests that this is the major factor affecting depreciation, but in cases where lighting is scarcely used in the light seasons it may well be decided to carry out maintenance only immediately preceding and during the dark season, in which case the effect of lamp operation on the rate of depreciation will assume greater importance. It is suggested that this point might well receive attention in future studies.

(4) Maintenance Considerations in Lighting Design

It has been stated earlier that economic considerations do not always determine lighting maintenance procedure and expenditure. Cleaning is often carried out only when the dirtiness of fittings has become apparent, just as lamp replacement is often delayed until lamp failures compel action in the matter.

This attitude to lighting maintenance is to some extent understandable since it is unlike most other plant maintenance which has a preventive function and the neglect of which may have very serious consequences. The consequences of neglecting lighting installations, however, are only regarded as serious by those who attach importance to the maintenance of a minimum service value of illumination. The proportion of factories where this applies must be very small indeed judging by the few in which lightmeters are regularly used, but this fact should not preclude a study of maintenance in relation to the design of new installations and of lighting equipment.

(4.1) Maintenance Factors

It is customary to base lighting design calculations on an arbitrary Maintenance Factor, usually 0.8, and on the average light output of lamps throughout life. This latter convention works out fairly well when lamp replacement is casual, since normal variations in lamp life eventually cause a random scatter of new and old lamps over an area and the average illumination at any time should be well in accordance with that predicted by this design method. Where group replacement is to be applied there is a case for including in the maintenance factor provision for the fall off of illumination given by a lighting layout as the lamps age. It is doubtful, however, whether such precision is realistic in view of the uncertain relationship between the hours of lamp operation and elapsed time. In any event, the tendency for longer lamp life and better ageing characteristics is reducing the importance of this factor.

It would appear also, from the information available, that the value of 0.8 provides a reasonable allowance for lighting installations in fairly clean locations, having regard to the incalculable factor of decorations and taking the least optimistic view of fittings cleaning schedules.

In the case of dirty locations, or high bays and other locations where cleaning is likely to be very infrequent, the optimum maintenance factor is bound up with the cost of cleaning the fittings, the maximum variation in illumination that can be tolerated and the depreciation characteristics of the reflectors used. Taking, for example, the installation on which Fig. 8 is based, a number of design alternatives suggest themselves:—

(1) Unventilated open fittings may be specified and:—

(a) A Maintenance Factor of 0.8 adopted.

It is obvious from Fig. 8 that the designed service value could only be maintained by cleaning reflectors once monthly. This is unrealistic and such an installation would be unsatisfactory either through failure to provide the specified illumination or through excessive cost of cleaning; or

(b) A Maintenance Factor of 0.7, or even 0.6, may be adopted.
This is a more realistic course but is open to the objections that the capital and running cost (excluding cleaning) is thereby increased in the ratio 0.8 : 0.7, i.e., by 14 per cent. or 0.8 : 0.6, i.e., 33 per cent over scheme 1(a). Also, the variation in illumination between cleaning dates will be very noticeable.

(2) Ventilated open fittings may be used, in which case a Maintenance Factor of 0.8 is realistic even though cleaning may take place only once per year. A reasonably economical and satisfactory installation should result from this specification.

A further alternative would be to adopt completely enclosed vapour and dust proof fittings. This would increase the capital cost by a considerable sum but would be justified in corrosive or other extremely bad situations, such as the presence of oily dust, where even ventilated fittings would be unsuitable.

A comparison of (1)(a), (1)(b), and (2) indicates the importance of choosing fittings with suitable depreciation characteristics and basing the Maintenance Factor on these characteristics, and on a realistic forecast of cleaning intervals.

(4.2) Maintenance Considerations affecting Fittings Design

It has been said that one advantage of the term " Maintenance Factor " over the term " Depreciation Factor " is that the former term suggests that maintenance is up to the user whereas the latter suggests that deterioration is inevitable. In so far as the real cost of depreciation is concerned, however, there is something to be said for the earlier method of adopting a multiplying factor in design calculations instead of the present dividing factor; a multiplier of 1.25, for instance, gives a truer picture of the cost of depreciation than a divisor of 0.8, although both amount to a 25 per cent. addition to the basic cost of lighting. The further costs of fitting, cleaning and lamp replacement may bring the total cost of depreciation to at least one-third of the total expenditure on lighting. Alternatively, it may be more realistic to state that depreciation is, at the present time, increasing the cost of *useful* light by at least 50 per cent.

The authors' observations, arising out of visits to a wide variety of factories, suggest that this is most probably an underestimate. Grime-encrusted reflectors are a familiar sight, even in progressive plants, and instances of systematic maintenance are few. It would seem to be wise to accept this situation and to concede that the lighting industry will best serve the interests of its clients, and of lighting generally, by examining carefully the respective claims of initial efficiency and light maintenance characteristics of lighting fittings to see whether the best balance is being achieved.

The standard dispersive reflector is a case in point. It has for many years carried the main burden of industrial lighting on account of its simplicity, ruggedness and cheapness. The combined lamp and fitting has a relatively high initial efficiency of approximately 70 per cent., and a minimum possible efficiency, after depreciation, of approximately 40 per cent. since this percentage of light output comes directly from the lamp. The reflector alone, therefore, contributes initially some 30 per cent. of the total fitting output, an appreciable percentage of which is due to specular reflection from the vitreous enamel, which is lost in the early stages of depreciation. When these reflectors are in service for periods of a year or even more without attention in average factory conditions it is unlikely that they reflect, over the average cleaning period, more than about 15-20 per cent. of the total lamp output. It might well be considered whether an open top releasing up to 30 per cent. of the lamp output to the upper hemisphere, and greatly improving the maintenance characteristics of the remaining

reflecting surface, would not provide, on average, at least as much downward light, with the added advantage of better brightness distribution.

It is noticeable that there is an increasing tendency to provide generous top openings in reflectors housing high wattage lamps. Impetus has been given to this, no doubt, by the problem of heat dissipation but it is suggested that the same principle might well be applied to all but totally enclosed reflectors with a consequent gain both in useful light obtained and in lighting quality, at little or no greater first cost to the user.

(5) Conclusions

It has not been possible in this paper to do more than present the maintenance problem and, as regards fittings depreciation, to report the results of work done by others. It would be misleading to offer generalised rules for maintenance or even to suggest that maintenance can ever be rationalised to that extent, but the information collected in this paper is sufficient to enable a number of conclusions to be drawn, and these are set out in the following:—

(1) The steady improvement in uniformity of fluorescent and discharge lamp characteristics combined with increases in life are making group lamp replacement both more practicable and more economically attractive.

(2) The advantage of group replacement is most marked when it can be combined with a planned scheme for cleaning.

(3) Reflectors depreciate most rapidly in the early stages, after which depreciation occurs much more slowly. This suggests that the cleaning interval is only critical when it is intended to limit the *initial* rapid depreciation by very frequent cleaning.

(4) The effect of ventilation is decisively to improve the lighting maintenance of all types of open fittings. In most industrial interiors the use of correctly ventilated fittings will avoid the necessity for frequent cleaning of fittings, and will permit the adoption of a maintenance factor of 0.8 with a reasonable safety margin.

(5) Enclosed fittings which are not hermetically sealed are likely to suffer greater depreciation than ventilated open fittings. They are less susceptible to oily dirt than to dry dust.

(6) There is scope for further investigation into the effect of lamp operation on the rate of fitting depreciation, with a view to establishing the relative importance of elapsed and operating time as factors in determining cleaning schedules.

(7) Having regard to the likelihood of the average factory fitting being cleaned at intervals of a year or even more, a balance should be struck between the requirements for high initial efficiency and for good light maintenance, i.e., self cleaning properties. In particular it is suggested that serious consideration should be given to the incorporation in the standard dispersive reflector of provision for ventilation, which will also allow the escape of up to 30 per cent. of lamp light upward. There appears to be little justification for the use of unventilated, opaque top fluorescent reflectors except for special cases where upward light is undesirable.

(8) Maintenance considerations should be a primary design factor having regard to the high cost of allowing for excessive depreciation in the Maintenance Factor or, alternatively, the unsatisfactory lighting performance obtained from an installation whose depreciation exceeds that allowed for in the Maintenance Factor.

Acknowledgments

The authors wish to acknowledge their indebtedness to the workers on this subject both in this country and the United States, whose results they have freely used, and particularly to Mr. J. G. Holmes for information regarding prismatic reflectors and to the Research Laboratories of the General Electric Company for their courtesy in releasing research data in advance of publication.

Discussion

MR. A. N. IRENS: I welcome the opportunity of opening this discussion because this is a very vital matter which has been brought before us and I for one confess that I have been very negligent over many years in looking at the economics. We have been inclined to take up all our time planning new installations and leaving it to the chap in the shop to carry on with the maintenance with no very explicit instructions.

When I first heard of the paper and read some advance information on it I started making enquiries. I found in the shops which come under my responsibility various practices. In some cases the local maintenance man in a particular shop will have a small stock of lamps and a few starter switches and will go round and replace the lamps when they go out; he invariably cleans the reflector at the same time. In other cases there is a certain amount of planned lamp replacement and cleaning.

I should like to divide the problem into two and to confine my remarks to industrial lighting. As far as metal filament lamps are concerned I have some figures. I find the actual cost of replacing lamps and cleaning fittings in various shops is as follows (it apparently costs just as much to clean whether a new lamp goes in or not, it is getting up to the lamp which takes the time):—

at 11 ft. headroom ..	1s. 3d. a point
20 ft. headroom ..	2s. 6d. a point
28 ft. headroom ..	6s. a point

On enquiry I find that the last figure is high because the work has to be done at week-ends which of course puts up the cost; the cost is less if the cleaning can be done in normal working hours.

What should be done? I find it difficult to say. On the metal filament side I cannot really see that there is a case for group replacement and cleaning. No doubt other speakers in the discussion will give us more information.

According to the curves shown on depreciation due to dust, if you are going to keep up a standard you must clean about once a week. I do not think in practice that we can make a case for cleaning other than at the time when lamps are replaced.

I was particularly interested to see the difference between ventilated and enclosed fittings; clearly there is a strong case for good air movement. I would suggest that the fitting should be totally enclosed, really hermetically sealed.

If only the lamp industry could get down to providing these internal silvered metal filament lamps with a life and efficiency which would give ordinary general service at a reasonable price! We should then have no need for reflector fittings and would just throw the thing away when it was finished. But I dare say that as metal filament lamps are going out in industry it is not worth diverting research in that direction.

With fluorescent lighting, I think there is a better case for group replacement. I find we have been doing this quite a bit. We have got quite a few installations with time meters fitted so that every time the switch is put on the time meter shows the number of hours. Those fluorescent lamps changed in batches give well over 5,000 hours of life. The principle worked on is that when, with a row of 100 lamps, five or 10 give out, the lot are changed. But in that connection I find that the starter switches are a major problem and there is a tendency to install instant start gear in all new installations.

A main factor with fluorescent lighting is the fact that the lamps will go on burning to very low values of light output, and as the cost of the lamp itself is only a small part of the total cost of providing light I think that replacement at regular intervals is the proper way of dealing with fluorescent lamps.

I seriously wonder whether, with the high intensities we want to-day, in many

factories where the roof structure lends itself and where there is a certain amount of material cut-off rows of bars fluorescent lamps with a white roof is not the answer.

MR. M. KRANTZ: I find this paper particularly interesting because of my close association with these two problems of lamp replacement and cleaning. My remarks will be confined to fluorescent lighting and Sections 2 and 3 of the paper, and will, I believe, serve a useful purpose if they tell of some of the experiences of my Company and how we have come to adopt our present policy.

We went through the stage, some three or four years ago, of replacing lamps as they failed, and as a continuous process this was most unsatisfactory, to say the least. The "random scattering" of lamps of varying vintages over a sales floor together with the constant attention needed to the replacement of lamps, prompted us to investigate this problem further. The published claims of lamp life and maintenance were not acceptable on their face value, and we preferred to be like the good student and start from first principles, i.e., to find out for ourselves how the fluorescent lamp operated under our own field conditions.

Extensive tests were carried out in a number of stores having a total of about 2,000 lamps, and from the mortality curves obtained it was concluded that bulk replacement on the basis of percentage failures had the greater virtue. Our system of monthly recording, in London, of the failures in all fluorescent stores was highly conducive to this basis, since the condition of every installation, as regards lamp failures, was known at all times.

We found that about 20 per cent. of failures was as much as we were prepared to tolerate, bearing in mind the high rate of failure which corresponds to this figure. The importance of the shape of the mortality curve becomes apparent here, and depending on the make and batch of lamps, the range of percentage failures can extend from about fifteen to twenty-five. In fact, the results of this year's activities might be interesting. Twenty stores were re-lamped in the twelve months, the average percentage failures and life being 15 per cent. and 4,250 hours (17 months) respectively. Fifteen per cent. may sound low, but I repeat that it is an average. A high standard is maintained and other factors have to be considered.

I would like to ask Dr. Strange at this stage whether his reference to 7,000 hours was hypothetical. My experience is that this figure has yet to be attained.

Costs related to lamp replacement might also be of interest. Individual replacements involve, on average, about one man-hour of labour, perhaps 3s. 6d. or 4s. For bulk replacement, using London skilled labour throughout the country, the cost works out at just under 11d. per lamp.

Referring to Section 3 dealing with cleaning, as much as it would be advantageous to combine cleaning with lamp replacement, the methods used for the two operations may not always allow for this. In our case, the washable portion or louvred diffuser is removable and a number of fittings is cleaned each day. If bulk replacement and cleaning of fittings take place at the same time it would be more by coincidence than design. In our view, incidentally, the removability of the diffuser in a simple manner should be an important prerequisite to the manufacture of a lighting fitting. Our costs of 30s. per fitting per annum should support this view, as many installations with large numbers of fittings can account for considerable expenditure for cleaning.

Reverting back to the introduction, I do agree with the authors about the difficulty of assessing accurately the effects of clean and dirty interior surroundings. We have been able to record, on a number of occasions, that a simple washing of walls and ceilings improves the lighting by as much as 20 per cent., whilst complete repainting brings about an increase of up to 30-35 per cent. Although it might be irrelevant to this paper, a change from a wood to terrazzo floor shows results equally remarkable.

MR. A. H. COLE: I am very grateful for the opportunity to hear this paper since we, on the railways, are at present very much concerned with lamp replacement and the cleaning of lighting fittings. In the many and varied types of lighting installations required for railway purposes we are faced with all the difficulties associated with inaccessibility and atmospheric pollution.

The paper has served to confirm the impression which I had already formed that the investigations into the economics of the cleaning of lighting fittings have so far only touched the fringe of the problem and that there is great scope for further work. Research of this nature on the railways would be a formidable undertaking since the rate of fitting deterioration depends on such varied factors as weather conditions, geographical situation, pollution of atmosphere, type of fitting, type of illuminant and even upon burning hours. I should like to ask the authors whether, in the light of their own researches, they consider that it would be possible to produce a series of curves showing how the monetary loss attributable to dirty fittings varies with the frequency of cleaning and so deduce, for each type of installation, the economic frequency of cleaning.

From the survivor curves shown by the authors it appears that the form of the curve is similar for both tungsten filament and tubular fluorescent lamps. Are the survivor curves for all types of discharge lamp also similar in form to those shown?

In their suggested procedure for group replacement of lamps after a given percentage failure the authors say that the marked replacement lamps may be used once more only. This appears to be conservative and I would suggest, making due allowance for damage resulting from frequent handling, they could be used, on the average, three times in all.

MR. W. A. R. STOYLE: Having presented a paper on the maintenance of fluorescent installations to this Society some five years ago, I have been looking forward to this lecture but I am disappointed that the authors have not been able to give rather more factual information on the maintenance costs of different types of installation.

The group replacement principle is not by any means new, having been applied to streetlighting for about thirty years. Group replacement in industrial installations has not been generally employed for the following reasons: (i) even within the compass of one installation the burning hours may differ very widely, (ii) the effect of vibration, particularly on filament lamps, may alter completely the shape of the survivor curve shown by the authors, and (iii) lamp life may be widely influenced by local variations in mains voltage caused by transient alterations of the factory load.

It should not, therefore, be assumed that all interior installations are suitable for group replacement, but there are undoubtedly many installations where the practice could be applied with advantage.

MR. A. E. FOTHERGILL: This has been a most interesting paper on a subject which has received little attention in the past.

My first point refers to the argument made by the authors in the introduction that a faulty fluorescent tube may, if left unattended, cause damage to the starter switch and ballast. Whilst this does apply to the starter I do not think it applies to the choke. A recent draft B.S. specification covering control gear for fluorescent tubes lays down a stringent test for fault conditions such as stuck starter switch and any well-designed ballast will withstand this. Surely a works engineer would not be happy with a ballast that is liable to give trouble unless he can give immediate attention to a faulty tube or starter switch.

Under Section (2) on lamp replacement details are given of the lamp costs for an installation of 240 tubes. It would, I think, help to provide a more realistic picture if the authors could state if the labour was skilled or unskilled. I was surprised to learn that the advantages of ventilation applied equally to fittings which run relatively cool

as to those which run relatively hot. Does a fluorescent trough with a slotted reflector constitute a ventilated fitting and would it show a definite advantage over a closed trough in a dirty or dusty location?

The results of the tests on cover glasses was revealing and I think that the authors have quite rightly drawn our attention to the fact that we tend to use the maintenance factor of 0.8 rather willy-nilly. Although we may make some attempt to allow for dirty locations, I wonder how many of us would have reduced the maintenance factor to 0.66 in an office installation employing translucent glass reflectors with unsealed cover glasses.

One point which the authors have failed to cover in Section (4) concerns the maintenance facilities provided on fittings. I refer to overlamp reflectors for tungsten lamps, detachable reflectors with or without lamps for fluorescent fittings, access to starter switch and control gear, ease of lamp replacement and cleaning. These facilities often appear sound on paper but do not always work out at the top of a ladder where the electrician has to perform a balancing feat worthy of a circus act to carry out his maintenance. Has everything possible been done in this direction and have all so-called facilities proved worth while? I am sure we will be most interested to have the authors' and other engineers' views on this aspect.

MR. W. J. SMITH: The figures given for group replacement and cleaning are interesting, but as a manufacturer of surface coatings I would like to know how lighting fittings are cleaned. Common surface coatings on lighting fittings are vitreous or stove enamel, which are quite different surface films. A lot of time and money is put into a complete lighting installation which may be ruined by ignorance on methods of cleaning. Harsh scourers can remove the surface and expose the metal, which then corrodes; most dirt can be removed with ease by the use of modern detergents. Manufacturers of fittings ought to give some guidance on how their fittings should be cleaned.

MR. S. ANDERSON: Lighting engineers not infrequently are called upon to present an economic comparison between different lighting systems, and while they are well aware that one of the factors in the economics is that of lamp replacement, it is seldom that data on this point are obtainable. I therefore feel that the costs given by the opener and second speaker in the discussion are valuable. It would make them still more useful if it could be made quite clear whether they are total costs, including a due proportion of overhead expenses, or simply the bare cost of the maintenance man's time, and I hope the speakers will add this detail in the record of their remarks.

The commonly used maintenance factor of 80 per cent. has been quoted by the authors, and while I realise that any one figure must necessarily be an average, I should be interested to hear whether they consider 80 per cent. to be a good average for general use. I am inclined to feel it is probably a little too optimistic.

But with the higher levels of illumination generally existing to-day, I wonder whether we need to be so critical of the fall off in level which occurs as the authors have indicated. After all, the lighting installation is there for the purpose of enabling people to see in the great majority of cases, not merely to produce a certain reading on a meter. While a fall of 30 or 50 per cent. may seriously impair vision when the initial level is low, a similar percentage fall in the case of an initial 20 or 30 lm/ft^2 is not nearly so serious in its visual effect.

MR. R. C. DRAIN: I should prefer to call the paper "Maintenance of Illumination" rather than "Maintenance of Lighting Installations," as the authors have not attempted to deal with the electrical maintenance of lighting installations

London Transport has been mentioned by the authors in their paper, and a few notes on the practice in the railway division of London Transport may be of interest.

London Transport takes a great pride in the appearance of its stations, but from an illumination point of view its main concern is the safety of the passengers. Staff are available 24 hours every day to deal with inaccessible lamp replacements and electrical maintenance. Inaccessible lamps are those which cannot easily be changed during normal traffic hours by the station staff.

Group replacement is applied only to fluorescently lit underground stations, and the principal reason for this is one of appearance. At these stations each alternate lamp is changed every six months, i.e., after a lamp life of some 4,000 hours, as the lighting of these stations is generally in use 24 hours a day. Consideration is being given to the extension of the six-month period to take advantage of the improved life and efficiency maintenance of modern fluorescent tubes. Alternate lamps are changed in order to maintain the level of illumination.

Group replacement of tungsten lamps is not carried out, although investigations into such group replacement have been made. If it were adopted there is little doubt that the saving in labour costs would outweigh the additional material charges for lamps and would undoubtedly result in a better appearance.

Lighting installations at stations are cleaned regularly every seven weeks by a semi-skilled gang, to which are attached a pair of electricians to immediately deal with any electrical fault. The cleaning schedules are, in all cases, based on elapsed time and not on operating time. Throughout the system the condition of lighting fittings varies and is so bad in places that it has been necessary to use rust remover to clean the accumulated brake dust from glass wire. All maintenance foremen are equipped with pocket light meters.

MR. J. MORTIMER HAWKINS: I feel that I owe to this meeting, and especially to the authors, an explanation as to why the threat contained in the original notification of the meeting has not materialised. I refer to my participation—or rather, my non-participation—in the preparation of this paper.

The authors were kind enough to simplify my task by sending me a draft of their paper and asking me to develop the contractor's point of view. Believe it or not, even this simple task beat me—and for two main reasons. First, my experience is confined to a relatively large number of relatively small installations—installations spread over some hundreds of establishments ranging from six to a thousand fittings, with an average of about thirty, which, I believe, is possibly representative of many contractors' responsibilities. This is, of course, fundamentally different from the authors' approach, and the examples which they give in the sixth paragraph of their paper. Indeed, these examples indicate the existence of a domestic staff, which from a convenience point of view may have much to recommend it, but which from a cost point of view can never be very realistic. Domestic staff called on to perform some lighting maintenance function may otherwise be doing nothing, in which case labour allocation need be nothing, or at most merely nominal. On the other hand, such staff may be hard pressed, making it necessary to delay some other important and urgent work, with results which may well be catastrophic and very costly. The installation which in the third paragraph of the "Lamp Replacement" section is described as "typical" is in my type of activity essentially non-typical—and I would add my submission to this meeting that it is non-typical of the general problems of maintenance which I think concern industry and commerce in general, and the lighting industry in particular.

My second reason for being beaten is my complete failure to accept an approach by formula to what I think are *ad hoc* problems. In my view the authors' approach is too theoretical, resulting in an advocacy of organised lamp replacement which is so complicated as to make the tail wag the dog. I believe in organised maintenance,

and have attempted to achieve this over a fairly wide field for many years; but I remain convinced that a different approach is necessary as between one office block and another, as between one factory and another. I think maintenance procedures depend on the nature of the production in a factory—clean or dirty, dusty or dust-free; on its location—town, country or suburb; and by no means least, on the convenience of the occupier of business premises, remembering that normally such occupation is for the purpose of carrying out certain work profitably.

I do, of course, thank the authors for the time and thought they have given to the preparation of this paper; and I believe that the main effort of the industry should be directed towards convincing users, whose preoccupations are usually elsewhere, that the effective maintenance of lighting installations is of no less importance than the original installations. And will you forgive my adding that contractors could make a bigger contribution in this direction were it not for other policies which encourage, in some people's view quite wrongly, the establishment by users of real or imaginary domestic electrical staff.

MR. A. CUNNINGTON: (written contribution): Mr. Irens' concluding suggestion that perhaps it would pay him to abandon the fittings that are so costly in both installation and maintenance and use bare fluorescent lamps with a sprayed ceiling to give background reflection, did not seem to be taken very seriously, but does not this point to one way—even if a rather negative one—in which maintenance costs can be reduced, i.e., by using always the simplest possible units and avoiding any "gadget" which may be theoretically sound but under practical conditions does not justify itself. Are not many modern lighting installations ruined by over-elaboration? One can understand that in commercial premises a "showy" installation may have sales value and also fashion must be complied with, but when we are dealing with industrial premises where the *raison d'être* of the lighting is to increase the efficiency of the factory, all unnecessary extras should be barred. In fact the services of a consultant with balanced judgment seem desirable in order to curb the enthusiasm of the manufacturers for their latest stunts! London Transport have shown us by the bare fluorescent lamps in their white-tiled subways how futile a costly trough reflector or moulded plastic covering can be in certain circumstances, and it is probable that these conditions are more common than we are led to believe. The supposed glare from fluorescent tubes is to many people non-existent in those situations where good reflecting surfaces provide a suitably bright background. Let us simplify our installations and so reduce maintenance costs.

DR. R. G. HOPKINSON (written contribution): In the course of investigations into school and office lighting, it has emerged that the maintenance of the lighting is one of the deciding factors in the choice between filament and fluorescent lighting. The choice is not always based on matters of illuminating engineering at all. In Sweden just recently, for example, I was told that some education authorities find that their regular cleaners are not prepared to dust or rub over, still less thoroughly clean, fluorescent fittings, although they don't object at all to cleaning filament fittings. I believe this also happens in this country, too. As a consequence, fluorescent fittings, if installed, go for months without cleaning until they are serviced by skilled electricians. We know of course that replacement of fluorescent lamps and auxiliaries is a matter for an electrician, whereas a cleaner can replace a filament lamp.

The question arises, therefore, can designers of fluorescent fittings, lamps and auxiliaries look forward to producing a fitting, so self-contained, perhaps totally enclosed, so reliable in all its components, and of such a simple and knob-free and louvre-free design that it can be kept clean and in good order by unskilled cleaners?

This naturally demands group replacement of lamps, which has much to recommend it in schools and offices. If such a fitting could be produced, it would be worth sacrificing some lumens per watt to achieve it.

THE AUTHORS (in reply): We would like to thank those who have contributed to the discussion. Our intention was to produce a paper which would stimulate discussion and we are very grateful to those who have helped in such an interesting way to make this possible. Our second intention was to stimulate further inquiry into this subject and we hope that this will only be the first of a number of papers on this and allied aspects of the problems of maintenance.

Mr. Irens' contribution was most valuable in illustrating some of our main points. His figures were particularly interesting in giving precise details on the cost of some operations, which in our experience is all too seldom available. They were particularly useful in showing the critical importance of height. Fittings above about 20 ft. cost much more to service and clearly call for group replacement of lamps.

Both Mr. Irens and Mr. Cunnington have referred to the increasing possibility of relying on the roof structure for reflection and using bare lamps. There are several instances of this practice which appear to be quite satisfactory and, no doubt, it has possibilities for the future, particularly in the case of shell concrete or vaulted roofs. We must not forget, however, that ceilings suffer depreciation just as do reflectors, and frequency of cleaning or painting must be considered in relation to the maintenance factor adopted.

The actual field experience of Mr. Krantz in the many installations with which he has to deal was most interesting and it was most reassuring to find that, from his excellent detailed records of the maintenance of these installations, he had come to very similar conclusions as those derived from our more theoretical approach. Regarding his inquiry about lamp life, 7,000 hours has been regularly obtained on a standard three-hour switching cycle and is far from hypothetical.

Mr. Krantz has pointed out the importance of the surroundings as a factor in light maintenance and his remarks regarding the effect of lightening the floor are particularly applicable to industrial interiors where the provision of a light working area will undoubtedly affect the light utilisation considerably.

With reference to Mr. Cole's inquiry about mortality curves for other discharge lamps, we can state in general that they are similar to the one given in the paper, but we have, at present, insufficient data of life tests under control conditions to give detailed information. Many lamps need to be life-tested on a definite switching cycle to meet this requirement. We agree with Mr. Cole's point that we have been rather pessimistic in limiting marked replacement lamps to one every period of use only.

Replying further to Mr. Cole, we think it unlikely that the economics of dirty fittings can be usefully generalised upon. This possibility was examined in the course of drafting the paper and we were driven back to the conclusion that it was just not practicable to attempt such an analysis due to the enormous variation in circumstances in different premises.

The absence of factual information on maintenance costs referred to by Mr. Stoyle is due to the difficulty of separating out these costs and the fact that even when it has been done for any particular case it cannot be said that such costs are in any way typical. It seems impossible to treat maintenance costs other than on an *ad hoc* basis.

We agree with Mr. Stoyle that there are a number of installations where group replacement is difficult to apply, but there are many more where it can be done with advantage.

In reply to Mr. Fothergill's first point, some lamps near the end of their life lose their thermionic emission more at one end of the lamp than the other, and then

it may act as a rectifier, passing a substantial D.C. component. On occasion this may cause severe overheating above that allowed for in the draft specification if the lamps are left on for long periods. The quoted figures given for cost were based upon skilled labour.

In reply to Mr. Fothergill's further points, there is no doubt that a fluorescent trough with a slotted reflector constitutes a ventilated fitting, and Fig. 7 shows quite clearly its advantage over the closed top trough reflector. There is no doubt, however, that the design of a ventilated reflector for the maximum cleaning effect deserves further investigation, and the slotted top may not necessarily be the best form of ventilation.

The fact that no reference has been made to practical factors of lighting fittings must be attributed largely to the authors' desire to keep the length of the paper within reasonable bounds. It is hoped that this deficiency might be made good in a later paper or papers such as undoubtedly will be very welcome on this important subject. We certainly think that easy maintenance facilities as now provided are worth while.

We are indebted to Mr. Smith for his timely warning regarding the care needed in the materials for, and methods of, cleaning fittings to avoid surface attack.

In reply to Mr. Anderson we have stated in the written paper that the figure of 80 per cent. appears to be reasonable for fairly clean installations on the basis of the very casual maintenance that is so often the rule. We do not entirely agree with his suggestion that we can be more tolerant of depreciation in installations where the illumination is high. After all it is the percentage with which we are concerned and if it should be decided that a high level of illumination is required then clearly a quite high standard of maintenance must also be required. We come back to the fundamental economics of maintenance which is whether to design for a high maintenance factor and maintain accordingly or whether to assume a low maintenance factor and increase the initial illumination accordingly. This problem is quite independent of the actual level of illumination.

Mr. Drain hit the nail on the head when he suggested that the paper would have been better entitled "Maintenance of Illumination." The title was chosen and published before the paper took its final shape. We are very indebted to him also for his useful remarks on maintenance practice in London Transport, and were particularly gratified to note that all maintenance foremen are equipped with pocket light meters.

Mr. Cunnington's plea for simplicity deserves every support. He will, of course, agree that the conditions under which bare lamps are used by London Transport are particularly favourable having regard to the shape of the ceilings, the fairly extensive use of glossy tiles, and the excellent state of maintenance in which surfaces are kept on the Underground.

Dr. Hopkinson's comment on the difficulty of maintenance by unskilled personnel is most pertinent and, although manufacturers have in recent years advanced greatly along the path of easy maintenance, there is still some way to go in making fluorescent lighting as attractive as tungsten filament lighting from the maintenance point of view.

Mr. Mortimer Hawkins sought to exclude the type of installations with which he deals from the scope of the paper, but we feel that they fall clearly in the category of "horizontally inaccessible units" where the time necessary to get to the site with all the necessary spares represents a high proportion of the cost, and careful planning is essential to keep the cost down.

Additions to the List of Members

The following applicants have been duly elected by the Council to membership in the Society and their names have been added to the list of members:—

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